

Description

ETCHING OPENINGS OF DIFFERENT DEPTHS USING A SINGLE MASK LAYER METHOD AND STRUCTURE

BACKGROUND OF INVENTION

[0001] Technical Field

[0002] The claimed invention relates generally to semiconductor products and more specifically to the selective etching of high aspect ratio openings using a single mask layer.

[0003] Description of Related Art

[0004] In the manufacture of semiconductor devices, individual components must be interconnected to perform functions. Generally, this is accomplished by the introduction of conductive materials into openings in the silicon substrate between the individual components.

[0005] A common process by which such interconnections are made is the damascene technique, whereby openings are selectively etched into a dielectric layer covering the indi-

vidual components. Generally, a photoresist material is layered onto the dielectric layer and a pattern of openings outlined in the photoresist layer using lithographic techniques. An anisotropic etch is then used to form the openings in the dielectric layer. The photoresist material is then removed. Where openings are to connect individual components on more than one level, it is necessary to selectively cover some openings with an etch-resistant mask layer, etch the dielectric layer, and remove the mask layer. Generally, such a process requires the use of more than one mask layer with varying resistances to the anisotropic etch processes. Finally, the openings are filled with a conductive material, completing the connections between the individual components.

- [0006] As the size of semiconductor devices has decreased, the width of the openings connecting them has necessarily decreased. As a result, it has become more difficult to fill high aspect ratio openings with the conductive material. There have been several inventions directed toward solving this problem. See, e.g., U.S. Patent No. 6,710,447 to Nogami.
- [0007] What has not been previously described, however, is the utilization of the high aspect ratio problem in selectively

etching openings of varying depths in a dielectric layer, thereby eliminating the need for multiple mask layers.

SUMMARY OF INVENTION

[0008] A semiconductor device with openings of differing depths in a substrate or layer is described, as are related methods for its manufacture. Through selective deposition of a single mask layer, whereby low aspect ratio openings are substantially coated while high aspect ratio openings are at most partially coated, subsequent etching of the layer is restricted to uncoated portions of the high aspect ratio openings. The result is a layer with openings of more than one depth using a single mask layer. In a second embodiment, the selective deposition of a single mask layer is utilized to etch a layer while protecting underlying structures from etching. In a third embodiment, the selective deposition of a single mask layer is utilized to etch an opening into a layer wherein the opening has a sub-lithographic diameter, i.e., the diameter of the opening is smaller than can be achieved with the particular lithographic technique employed.

[0009] A first aspect of the invention is directed toward a semiconductor device comprising a substrate, a device over the substrate, a dielectric layer over the substrate and the

device, the dielectric layer including at least one high aspect ratio opening and at least one low aspect ratio opening, a rim within the high aspect ratio opening, the rim being at the depth of the low aspect ratio opening, a diameter of the high aspect ratio opening being smaller below the rim than above the rim, and a coating material over the openings into the dielectric layer.

- [0010] A second aspect of the invention is directed toward a method of manufacturing a semiconductor device with openings of differing depths in a dielectric layer. The method comprises the steps of depositing a dielectric layer onto a layer having a plurality of devices; forming a plurality of openings into the dielectric layer, the plurality including at least one high aspect ratio opening and at least one low aspect ratio opening; depositing an etch-resistant mask layer onto the dielectric layer such that the etch-resistant mask layer substantially coats at least one low aspect ratio opening and at most partially coats at least one high aspect ratio opening; etching only the high aspect ratio opening; depositing a coating material into the plurality of openings.
- [0011] A third aspect of the invention is directed toward a method of protecting underlying structures during the

manufacture of a semiconductor device. The method comprises the steps of depositing an interlevel dielectric layer onto an encapsulating dielectric layer having a plurality of structures and residing atop a substrate, where the interlevel dielectric includes a material different from the material of the encapsulating dielectric; forming at least one high aspect ratio opening by removing the interlevel dielectric layer from between the plurality of structures without removing the encapsulating dielectric layer; depositing an etch-resistant mask layer onto the interlevel dielectric layer and exposed portions of the encapsulating dielectric layer such that the etch-resistant mask layer at most partially coats the high aspect ratio opening and substantially coats the remaining surfaces of the interlevel dielectric layer and the encapsulating dielectric layer; etching the encapsulating dielectric layer such that the high aspect ratio opening is etched through to the substrate; depositing a coating material into the high aspect ratio opening such that a connection is made to the substrate.

[0012] The above and additional advantages of the present invention will become apparent to those skilled in the art from the following detailed description and accompanying

drawings.

BRIEF DESCRIPTION OF DRAWINGS

- [0013] The embodiments of this invention will be described in detail, with reference to the following figures, wherein:
- [0014] FIGS. 1A to 1E show schematic cross-sectional views of a method for the manufacture of a semiconductor device according to a first embodiment of the invention.
- [0015] FIGS. 2A to 2E show schematic cross-sectional views of a method for protecting underlying structures while etching a dielectric layer according to a second embodiment of the invention.
- [0016] FIGS. 3A to 3D show schematic cross-sectional views of a method for the formation of an opening in a dielectric layer where the opening has a sub-lithographic diameter.

DETAILED DESCRIPTION

- [0017] In general, the device and methods of the claimed invention employ terminologies common to the manufacture of semiconductor devices. For example, an opening, as used in the following description and claims, may be a channel, via, hole, socket, valley, furrow, trough, duct, trench, or any other similar structure.
- [0018] Referring to FIG. 1A, a dielectric layer 10 has been de-

posited atop a substrate 6 and device 8 and has been etched to produce high aspect ratio openings 20 and low aspect ratio openings 30. Dielectric layer 10 can be of any material common to the manufacture of semiconductor devices, such as, e.g., silicon oxide, silicon dioxide, hydrogenated silicon oxycarbide, etc. High aspect ratio openings 20 in dielectric layer 10 preferably have diameters less than about one-half their depths, and more preferably about less than one-quarter their depths. Low aspect ratio openings 30 in dielectric layer 10 preferably have diameters greater than about one-half their depths, and more preferably have diameters greater than their depths.

[0019] Referring to FIG. 1B, an etch-resistant mask layer 40 has been deposited onto the dielectric layer 10. Etch-resistant mask layer 40 substantially coats the surface of the dielectric layer 10 and the walls 32 and bottoms 34 of low aspect ratio openings 30 in dielectric layer 10. Deposition of etch-resistant mask layer 40 into high aspect ratio openings 20 is partial, and generally limited to the upper portions of the walls 22. Preferably, no deposition of the etch-resistant mask layer is made onto the bottoms 24 of high aspect ratio openings 20, as such deposition may

preclude selective etching of high aspect ratio openings 20. Etch-resistant mask layer 40 can be of any type common to the manufacture of semiconductor devices, such as, e.g., Si, W, Si_3N_4 , SiO_2 , etc., provided it is less susceptible to etching than dielectric layer 10. Deposition of etch-resistant mask layer 40 can be by any means common to the manufacture of semiconductor devices, such as, e.g., physical vapor deposition (PVD), chemical vapor deposition (CVD), sputter deposition, etc.

[0020] Referring to FIG. 1C, application of an etch recipe selective to etch-resistant mask layer 40, but capable of etching dielectric layer 10, results in additional etching of the bottoms 24 of high aspect ratio openings 20 and the formation of second level high aspect ratio openings 50. The junction between a high aspect ratio opening 20 and a second level high aspect ratio opening 50 is distinguished by a rim 52, residing at the depth of the high aspect ratio opening 20 and resulting from the incomplete etching of the bottom 24 of high aspect ratio opening 20. In the situation where high aspect ratio opening 20 and second level high aspect ratio opening 50 are in the form of a channel, the resulting rims 52 are distinct members residing on either side of the channel. In the situation where

high aspect ratio opening 20 and second level high aspect ratio opening 50 are in the form of a via, the resulting rim 52 is a single circumferential member residing between the high aspect ratio opening 20 and the second level high aspect ratio opening 50.

[0021] Referring to FIG. 1D, a coating material 90 has been overlaid onto dielectric layer 10 and into low aspect ratio openings 30, high aspect ratio openings 20, and second level high aspect ratio openings 50. Coating material 90 can be of any material common to the manufacture of semiconductor devices. Where coating material 90 is to serve as a conductor, coating material 90 may be, e.g., copper, aluminum, tungsten, silicon, titanium nitride, etc. Alternatively, where coating material 90 is used to reduce resistance–capacitance losses, coating material may be a low K dielectric material. Coating material 90 may be deposited by any means common to the manufacture of semiconductor devices and capable of filling high aspect ratio openings, such as, e.g., CVD, etc.

[0022] Referring to FIG. 1E, in keeping with finishing steps common to the manufacture of semiconductor devices, the surface of the semiconductor device has been etched back or polished to remove any coating material 90 and etch-

resistant mask layer 40 deposited on the surface of dielectric layer 10. The polishing means can be any means common to the manufacture of semiconductor devices, such as, e.g., chemical-mechanical polishing (CMP), etc., while the etch back means includes, for example, wet or Reactive Ion Etching (RIE) techniques.

[0023] In accordance with a second embodiment of the invention, dielectric layers may be selectively etched while protecting underlying structures. Referring to FIG. 2A, a semiconductor device has been prepared, having an interlevel dielectric layer 110 deposited onto an encapsulating dielectric layer 120, which contains a plurality of underlying structures 130. Interlevel dielectric layer 110 has been etched to reveal high aspect ratio openings 160 between underlying structures 130 within encapsulating dielectric layer 120.

[0024] Underlying structures 130 may include channels containing conductive materials, such as silicon, tungsten, silicides, titanium nitride, copper, aluminum, etc. Interlevel dielectric layer 110 and encapsulating dielectric layer 120 may be of types common to the manufacture of semiconductor devices, but must be used in combinations such that interlevel dielectric layer 110 is capable of being

etched by an etching recipe which is incapable or only slightly capable of etching encapsulating dielectric layer 120.

[0025] Referring to FIG. 2B, an etch-resistant mask layer 170 has been deposited onto the exposed surfaces of interlevel dielectric layer 110 and the top surface 122 of encapsulating dielectric layer 120. Together, the vertical surfaces 112 of the interlevel dielectric layer 110 and top surfaces 122 of encapsulating dielectric layer 120 form low aspect ratio openings 150 similar to those in the first embodiment of the invention. Etch-resistant mask layer 170 substantially fills these low aspect ratio openings 150. Deposition of etch-resistant mask layer 170 into high aspect ratio openings 160 between underlying structures 130 within encapsulating dielectric layer 120 is at most partial, and generally limited to the upper portions of the walls 162, as depicted in FIG. 2B. Preferably, no deposition of etch-resistant mask layer 170 is made onto the bottoms 164 of high aspect ratio openings 160.

[0026] Referring to FIG. 2C, application of an etch recipe selective to etch-resistant mask layer 170, but capable of etching encapsulating dielectric layer 120, results in additional etching of the bottom 164 of high aspect ratio openings

160 and the formation of second level high aspect ratio openings 180. As depicted in FIG. 2C, second level high aspect ratio opening 180 has been etched through to substrate 100.

[0027] The junction between a high aspect ratio opening 160 and a second level high aspect ratio opening 180 is distinguished by a rim 182, residing at the initial depth of high aspect ratio opening 160 and resulting from the incomplete etching of the bottom 164 of high aspect ratio opening 160. In the situation where high aspect ratio opening 160 and second level high aspect ratio opening 180 are in the form of a channel, the resulting rims 182 are distinct members residing on each side of the channel. In the situation where high aspect ratio opening 160 and second level high aspect ratio opening 180 are in the form of a via, the resulting rim 182 is a single circumferential member residing between high aspect ratio opening 160 and second level high aspect ratio opening 180. The etch recipe used can be of any anisotropic type common to the manufacture of semiconductor devices, such as, e.g., RIE, etc.

[0028] Referring to FIG. 2D, a coating material 190 has been deposited over etch-resistant mask layer 170 and into high

aspect ratio opening 160 and second level high aspect ratio opening 180. Conductive material 190 may be one or more of any commonly used in the manufacture of semiconductor devices. Where coating material 190 is to serve as a conductor, coating material 190 may be, e.g., copper, aluminum, tungsten, silicon, titanium nitride, etc. Alternatively, where coating material 190 is used to reduce resistance-capacitance losses, coating material may be a low K dielectric material. Coating material 190 may be deposited by any means common to the manufacture of semiconductor devices and capable of filling high aspect ratio openings, such as, e.g., CVD, etc.

- [0029] Referring to FIG. 2E, in keeping with finishing steps common to the manufacture of semiconductor devices, the surface of the semiconductor device has been processed to remove any coating material 190 and etch-resistant mask layer 170 deposited on the surface of dielectric layer 110. This processing could be achieved by polishing, e.g., by CMP, or by a controlled etch back procedure using a chemical etch, e.g., RIE or wet etches, for each of the materials.
- [0030] In a preferred embodiment of the claimed invention, it is possible to produce an opening into a dielectric layer

wherein the opening has a sub-lithographic diameter. That is, the diameter of the opening is smaller than the smallest diameter opening achievable using current lithographic techniques. For example, the smallest diameter opening currently achievable with ArF 193nm lithography is about 80 nm for an isolated feature (subject to variability, of course, depending upon the pattern density and shape complexity).

- [0031] Referring to FIG. 3A, a photoresist layer 260 has been applied to a dielectric layer 210 and portions of the photoresist layer 260 removed using a lithographic technique, to include a pattern of openings to be etched in the dielectric layer. A first diameter 270 between remaining portions of photoresist layer 260 represents the smallest diameter achievable with the lithographic technique employed. A second diameter 280 between remaining portions of photoresist layer 260 represents a diameter greater than first diameter 270. The lithographic technique employed may be any of those commonly employed in the manufacture of semiconductor devices.
- [0032] Referring to FIG. 3B, dielectric layer 210 has been etched and the photoresist layer removed to reveal a high aspect ratio opening 220 and a low aspect ratio opening 230 in

dielectric layer 210. The diameter 270 of high aspect ratio opening 220 is equal to the smallest diameter achievable with the lithographic technique employed. The diameter 280 of low aspect ratio opening 280 is greater than diameter 270 of high aspect ratio opening 220.

[0033] Referring to FIG. 3C, an etch-resistant mask layer 240 has been deposited onto dielectric layer 210, substantially coating the top surface of dielectric layer 210 and the bottom 234 and sidewalls 232 of low aspect ratio opening 230, and at most partially coating the sidewalls 222 of high aspect ratio opening 220. Generally, coating of high aspect ratio opening 220 is limited to the upper portions of the sidewalls 222. Preferably, no etch-resistant mask layer 240 is deposited onto the bottom 224 of high aspect ratio opening 220.

[0034] Referring to FIG. 3D, the bottom 224 of high aspect ratio opening 220 not covered by etch-resistant mask layer 240 has been further etched to produce a second level high aspect ratio opening 250. The diameter 290 of second level high aspect ratio opening 250 is smaller than diameter 270 of high aspect ratio opening 220. That is, diameter 290 of second level high aspect ratio opening 250 is smaller than the smallest diameter opening achiev-

able with the lithographic technique employed.

[0035] While this invention has been described in conjunction with the specific embodiments outlined above, it is evident that many alternatives, modifications, and variations will be apparent to those skilled in the art. Accordingly, the embodiments of the invention as set forth above are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the invention as defined in the following claims.